The efficiency and distributional impacts of alternative anti-sprawl policies

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Abstract

This paper develops an analytical and numerical general equilibrium model to compare the efficiency and distributional impacts of development taxes, urban growth boundaries, property taxes and gasoline taxes. From an overall efficiency perspective, development taxes and urban growth boundaries are equivalent instruments and the most effective anti-sprawl policies. If the choice of anti-sprawl instruments is influenced by distributional considerations, our results suggest the preferred instrument is closely related to the *location* of land. We present distributional impacts of the four policies at the urban city core, the urban suburbs and rural area.

1. Introduction

Since the Second World War, the predominant pattern of urban growth in the United States has been one of low density and employment decentralization (Mieszkowski and Mills [18], Glaeser and Khan [15], Nechyba and Walsh [20]). In recent years however, "smart growth" initiatives have been implemented in response to urban sprawl[1]. These programs – typically implemented by local governments – are essentially strict "command-and-control" regulations based on the presumption that there is an "ideal" urban spatial structure and size. An urban

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[1] Attempts to limit urban growth or to change its form are motivated by three concerns – to preserve open space and foster urban development that is more clustered and aesthetically appealing, to reduce the cost of providing public services and infrastructure, and to reduce the dependence on the automobile and the externalities associated with its use (especially air pollution and congestion) – that have accompanied urban sprawl.

growth boundary is just an example of such policies. Another potential approach, often advocated by economists, encourages the use of market-based instruments such as taxes on residential development, property taxes and fuel taxes[2]. To guide policymakers in the choice of alternative instruments, this paper raises three questions: First, what are the overall efficiency effects of alternative policies to control urban sprawl? Second, how are the costs and benefits of these policies distributed across landowners in the city? And third, depending on the policy instrument, what is the optimal amount of land saved?

Using a consistent analytical and numerical general equilibrium framework, we examine the efficiency and distributional impacts of development taxes, urban growth boundaries, property taxes and gasoline taxes. We also discuss the optimal level of land preserved under these alternative policies.

Several issues motivate our work. First, while the existing models in the literature (e.g., Brueckner ([7], [8]), Engle *et. al.* [13] and Frankena and Scheffman [14]) have helped us to understand the motivation for growth controls in cities, they certainly provide little (if any) guidance for the choice of alternative anti-sprawl policies as well as their optimal levels. For example, Brueckner ([9], [11]) provided a conceptual framework to evaluate anti-sprawl policies and presented first-best policy prescriptions. In his work, sprawl arises due to three main market failures – the failure to account for the social costs of congestion, the failure to account for the benefits of open space and the failure to charge developers for the infrastructure costs associated with development. These studies provide a working concept of sprawl but do not examine the choice of alternative policy instruments, including second best instruments such as gasoline or property taxes. Therefore, there is a need to develop a framework that allows for systematic comparisons of different instruments and that decomposes the various channels of efficiency exploited by each instrument.

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[2] Transferable Development rights are another example of market-based instruments aimed at preserving land (see McConnell et al. [19]).

Second, while it is appropriate to suggest landowners are the winners from growth controls from an overall efficiency perspective, it may not be totally accurate to think of landowners as a 'group', which is equally affected by the control. One can think of a control imposed at the boundary of a city and the consequent increase in amenity; in this case one would expect that the *location* of the plot of the land would determine whether a specific landowner would experience a welfare increase. In fact the distribution of the costs and benefits of growth controls in *space* can be critical for the choice of anti-sprawl policies, yet it has been completely neglected in the literature. One would expect different instruments to have different "*spatial*" incidences, in which case certain landowners might prefer one instrument to another, and in turn lobby planning agencies for the implementation of certain policies. This insight may help us to explain an empirical regularity: that quantity controls (e.g. Urban Growth Boundaries) are more widely implemented than price controls (e.g. development taxes)[3].

The rest of the paper is organized as follows: Section 2 presents an analytical model that decomposes the efficiency and distributional impacts of the policy instruments. Section 3 presents the simulation model and section 4 provides the simulation results. Finally, section 5 offers conclusions.

2. The Analytical Model

This section develops an analytical model to compare the efficiency and the distributional impacts to different landowners throughout the city resulting from different anti-sprawl policy instruments. We examine the efficiency and distributional impacts of four policies – a tax per unit of residential land (development tax), an urban growth boundary (UGB), a property tax and a gasoline tax. Subsections A-E lay out the model assumptions and discuss the general equilibrium impacts of the different policy instruments.

[3] This is certainly the case in California Cities. For a recent study of the determinants of adoption of Urban Growth Boundaries in California, see Bento and Ahoobim [5].

A. Model Assumptions

We develop a static model of an open city in which a representative household enjoys utility from housing (H), a composite consumption good (Z) and open space (O). The household utility function is given by:

$$U = u(H, Z) + \phi(O) \tag{2.1}$$

where $u(\cdot)$ is utility from non-environmental goods and is quasi-concave and $\phi(\cdot)$ is utility from open space, which is concave[4]. The separability restriction in (2.1) implies the demands for H and Z do not vary directly with changes in O. The household budget constraint is:

$$Z + pH = Y - tx \tag{2.2}$$

where p is the rental price of H, Y is household income, t is the transportation cost per mile and x is distance, in miles, from the place of residence to the central business district (CBD). For simplicity, we set the price of the composite good equal to unity. Households choose x, Z and H to maximize utility (2.1) subject to the budget constraint (2.2), taking the level of open space as given. From the resulting first-order conditions and (2.2) we obtain the uncompensated demand functions for the composite good and housing, conditional on location x:

$$Z(Y, t, p, x) \text{ and } H(Y, t, p, x) \tag{2.3}$$

Substituting these equations into (2.1) gives the indirect utility function:

$$V(Y, t, p, O, x) \tag{2.4}$$

For any given structure of housing prices in the city, households prefer those locations that provide the highest level of utility. In equilibrium, the usual spatial arbitrage argument implies all

[4] We have modeled open space in a fairly simplified way and some caveats are in order. First, we think of open space as undeveloped land at the urban fringe. Second, we assume that households get utility from the existence of this open space, and abstract from transportation costs to the site. Third, we do not model open space inside the city. In a companion paper, we econometrically estimate households' valuations of different forms of open and evaluate the benefits of alternative open space policies (see, Bento et al. [6]).

locations that are occupied by households must have rents that allow a common level of utility $\overline{V}$ to be achieved. Therefore, a representative household chooses x that maximizes (2.4) and p adjusts so that:

$$V(Y,t,p,O,x)=\overline{V} \tag{2.5}$$

Equation (2.5) implicitly defines the housing bid rent function as:

$$p(Y,t,O,\overline{V},x) \tag{2.6}$$

Equation (2.6) describes the maximum rent, which a household is willing to pay at a particular distance from the CBD if it is to receive a given level of utility $\overline{V}$. Note that, given the assumptions of the utility function, it is the case that:

$$\frac{\partial p(Y,t,O,\overline{V},x)}{\partial O}>0 \tag{2.7}$$

Absentee landowners own land and maximize their return by deciding its use. We consider two possible uses of land: residential and agriculture. For simplicity, we assume an exogenous agricultural rent per acre equal to r_a. When land is allocated to residential use, the landowner combines land (L) with capital (K) to produce housing. Let $H^s(L,K)$ represent the constant returns to scale housing production function. Given that $H^s(L,K)$ is homogeneous of degree one, we can express the housing supply as a function of the capital-to-land ratio:

$$S=\frac{K}{L} \tag{2.8}$$

S is a proxy for housing density or building height and $h(S)$ denotes the housing output per acre of land satisfying $h'>0$ and $h''<0$. The return per acre of land in residential use at a particular location x is defined as:

$$r_u(Y,t,O,\overline{V},p_k,x)=\underset{S}{Max}\ p(Y,t,O,\overline{V},x)h(S)-p_kS \tag{2.9}$$

where p_k is the price of capital. At each location x, landowners choose the use that maximizes the return of their plot of land. Therefore, if the return in agriculture is less than the return in residential, a plot of land will be converted into residential use.

Finally, the two closing conditions of the model state residential land rent must equal the exogenous agricultural rent at the city boundary $(\bar{x})$:

$$r_u(Y,t,O,\overline{V},p_k,\bar{x}) = r_a \tag{2.10}$$

where r_a denotes the exogenous agricultural rent.

The city limit is established in the land market and is implicitly determined by (2.10) as:

$$\bar{x}(Y,t,O,\overline{V},p_k,r_a) \tag{2.11}$$

The second closing condition of the model requires equilibrium in the housing market at all locations. This means at a particular location x, total housing demand should equal total housing supply, and therefore, total population at location x is given by:

$$N(Y,t,O,\overline{V},p_k,x) = \frac{h(S(Y,t,O,\overline{V},p_k,x))}{H(p(Y,t,O,\overline{V},x),Y,t,O,x)} \tag{2.12}$$

and all households live in the city:

$$\int_0^{\bar{x}} N(Y,t,O,\overline{V},p_k,x)2\pi x dx = N \tag{2.13}$$

N denotes total population in the city. Note that $2\pi x$ in (2.13) implies a monocentric circular city.

With this framework, we can now analyze the efficiency and distributional impacts to different landowners of various anti-sprawl policies. To calculate the efficiency impacts of a policy, we note that prior to a policy intervention, total value of land in the city, R, is given by the sum of total value of land in residential use with total value of land in agriculture use:

$$R = \int_0^{\bar{x}} r_u(Y,t,O,\overline{V},p_k,x)2\pi x dx + \int_{\bar{x}}^{\overline{m}} r_a 2\pi x dx \tag{2.14}$$

where $\overline{m}$ denotes the geographical city boundary. The efficiency impacts of a policy are calculated as changes in the value of land resulting from a policy intervention. In order to provide systematic comparisons across policy instruments, all policy interventions aim to save the same amount of land (ΔO) and thus achieve the same city boundary. The amount of open space saved is given by:

$$\Delta O = \pi(\overline{x}^2 - \overline{x}_i^2) \tag{2.15}$$

with $\overline{x}_i$ the new city boundary under policy i and which is computed as[5]:

$$\overline{x}_i = \sqrt{\overline{m}^2 - O/\pi} \tag{2.16}$$

To analyze the distributional impacts of the policies we divide landowners into three main groups. First, we consider the set of landowners who allocate their land to residential use prior and post policy. Second, we examine the set of landowners who alter their behavior in response to the policy by not converting land. And finally, we consider the set of landowners who allocate their land to agriculture before and after the policy. Let the value of land for each of these groups of landowners be represented by R_1, R_2 and R_3 respectively, where:

$$R_1 = \int_0^{\overline{x}_i} r_u(Y,t,O,\overline{V},p_k,x)2\pi x dx \tag{2.17}$$

$$R_2 = \int_{\overline{x}_i}^{\overline{x}} r_u(Y,t,O,\overline{V},p_k,x)2\pi x dx \tag{2.18}$$

$$R_3 = \int_{\overline{x}}^{\overline{m}} r_a 2\pi x dx \tag{2.19}$$

In subsections B-E we provide and interpret key equations that decompose the effects of each policy. To illustrate the solution method applied to derive the efficiency effects of the policies, below we present step-by-step the derivations for the development tax. For the other instruments,

[5] Note that $O = \pi(\overline{m}^2 - \overline{x}^2) + \Delta O$. Substituting this equation into (2.15) and solving for $\overline{x}_i$ gives (2.16).

complete derivations are provided in Appendix A. We remind the reader that our goal is to compare the efficiency and distributional impacts of alternative policies aimed at saving the same amount of land.

B. Development Tax

Consider a revenue-neutral tax t_D per unit of residential land, with tax revenues redistributed lump sum to all landowners. Let g_{t_D} be the government transfer to each landowner under this policy. The first order condition of the maximization problem on the right hand side of equation (2.9) is given by:

$$p(Y,t,O,\overline{V},x)\frac{\partial h(S)}{\partial S} = p_k \tag{2.20}$$

Equation (2.20) implicitly defines the optimal density level as:

$$S(Y,t,O,\overline{V},p_k,x) \tag{2.21}$$

Substituting (2.21) into (2.9) and noting that each residential landowner has a net tax of $g_{t_D} - t_D$, the return per acre to land in residential use at location x under a development tax, $r_u^{t_D}(Y,t,O,\overline{V},p_k,t_D,g_{t_D},x)$, can be written as:

$$r_u^{t_D}(\cdot,x) = p(Y,t,O,\overline{V},x)h(S(Y,t,O,\overline{V},p_k,x)) - p_k S(Y,t,O,\overline{V},p_k,x) - t_D + g_{t_D} \tag{2.22}$$

The return in agriculture use under this policy is given by:

$$r_a + g_{t_D} \tag{2.23}$$

By setting $r_u^{t_D}(\cdot,x)$ in (2.22) evaluated at $x = \overline{x}_{t_D}$ equal to the return in agriculture use (2.23) and eliminating $\overline{x}_{t_D}$ from (2.22) using (2.16), we derive:

$$p(Y,t,O,\overline{V},\overline{x}_{t_D})h(S(Y,t,O,\overline{V},p_k,\overline{x}_{t_D})) - p_k S(Y,t,O,\overline{V},p_k,\overline{x}_{t_D}) - t_D - R_a = 0 \tag{2.24}$$

which implicitly defines t_D as a function of O. Therefore, in order to evaluate the efficiency effect of a development tax, the choice variable can be view as O instead of t_D, with a particular

O corresponding to a particular t_D. Differentiating (2.14) with respect to O taking into account (2.10), (2.20), (2.22), (2.23) and (2.24) yields:

$$\frac{dR}{dO} = \int_0^{\bar{x}} \left[\frac{\partial p(Y,t,O,\overline{V},x)}{\partial O} h\left(S\left(Y,t,O,\overline{V},p_k,x\right)\right) \right] 2\pi x dx - \left[\int_0^{\bar{x}} \frac{dt_D}{dO} 2\pi x dx \right] + t_D 2\pi \bar{x} \frac{d\bar{x}}{dO} +$$

$$+ \int_0^{\overline{m}} \frac{dg_{t_D}}{dO} 2\pi x dx \qquad (2.25)$$

(2.25) illustrates how total land rents vary with a marginal change in the amount of land saved through a development tax. A marginal change in the amount of land saved implies a change in the value of the policy instrument, which is captured by the second term on the right hand side of (2.25). In fact, the development tax is given by:

$$t_D = r_u(Y,t,O,\overline{V},p_k,\bar{x}_{t_D}) - r_a \qquad (2.26)$$

and the corresponding government budget constraint under a development tax is:

$$\int_0^{\overline{m}} g_{t_D} 2\pi x dx = \int_0^{\bar{x}_{t_D}} t_D 2\pi x dx \qquad (2.27)$$

Efficiency Effects of the Development Tax

The efficiency effects of a development tax t_D can be expressed as[6]:

$$\frac{dR}{dO} = \underbrace{\int_0^{\bar{x}_{t_D}} \left[\frac{\partial p(Y,t,O,\overline{V},x)}{\partial O} h\left(S\left(Y,t,O,\overline{V},p_k,x\right)\right) \right] 2\pi x dx}_{dR^{CO}} + \underbrace{(r_u(Y,t,O,\overline{V},p_k,\bar{x}_{t_D}) - r_a) 2\pi \bar{x} \frac{d\bar{x}}{dO}}_{dR^S} \qquad (2.28)$$

The term labeled dR^{CO} in (2.28) represents the *capitalization effect*. This effect is the gain associated with households responding to the higher level of open space by increasing their bids for housing. The *capitalization effect* equals the sum of the willingness to pay for open space by

[6] We arrived at this formula by inserting (2.26) into (2.25) while taking into account the government budget constraint in (2.27) must be balanced.

each household. The term labeled dR^S in (2.28) represents the *size effect*. This effect is the cost associated with the reduction in the total amount of land developed and is given by the reduction in the return of land due to the change in land use induced by the policy.

Distributional Impacts of the Development Tax

The distributional impacts to each of the different landowners' groups are respectively[7]:

$$\frac{dR_1}{dO} = \underbrace{\int_0^{\bar{x}_{tD}} \left[\frac{\partial p(Y,t,O,\bar{V},x)}{\partial O} h\big(S(Y,t,O,\bar{V},p_k,x)\big) \right] 2\pi x dx}_{dR^{CO}} - \underbrace{\left[\int_0^{\bar{x}_{tD}} \frac{dt_D}{dO} 2\pi x dx \right]}_{dR^T} + \underbrace{\left[\int_0^{\bar{x}_{tD}} \frac{dg_{tD}}{dO} 2\pi x dx \right]}_{dR_1^{TR}} \quad (2.29)$$

$$\frac{dR_2}{dO} = \underbrace{(r_u(Y,t,O,\bar{V},p_k,\bar{x}_{tD}) - r_a) 2\pi \bar{x} \frac{d\bar{x}}{dO}}_{dR^S} + \underbrace{\int_{\bar{x}_{tD}}^{\bar{x}} \frac{dg_{tD}}{dO} 2\pi x dx}_{dR_2^{TR}} \quad (2.30)$$

$$\frac{dR_3}{dO} = \underbrace{\int_{\bar{x}}^{\bar{m}} \frac{dg_{tD}}{dO} 2\pi x dx}_{dR_3^{TR}} \quad (2.31)$$

(2.29)-(2.31) suggest the development tax reduces the return to land in residential use uniformly throughout the city in the amount $dR_1^{TR} - dR^T$ and subsidizes the use of land for agriculture in the amount dR_3^{TR}. To the extent revenues from the development tax are being transferred to owners of agricultural land, it has to be the case that $t_D > g_{tD}$, and hence, the tax indeed penalizes residential use.

(2.29)-(2.31) also highlight several interesting effects regarding the distributional impacts of a development tax. First, all benefits from the *capitalization effect* (labeled as dR^{CO} in equation (2.29)) are captured by the landowners who continue to allocate land to residential use after the policy is in place. To this group of agents, the overall impacts of the policy consist of the

[7] By summing equations (2.29) to (2.31) and taking into account that the government budget constraint is balanced we arrive at (2.28).

capitalization effect and the *net tax effect* $dR_1^{TR} - dR^T$ in equation (2.29)). It is therefore not possible to determine the direction of the total effect to this group of landowners. In the particular case where the *capitalization effect* would dominate the *net tax effect*, these agents would experience a welfare gain under the development tax. Second, we note all costs from the *size effect* (labeled as dR^S in (2.30)) fall on the group of landowners who switch uses in response to the policy. These landowners are the main losers from this policy even though they are partially compensated in the amount dR_2^{TR}. Finally, we note landowners at the urban fringe benefit from this policy intervention. Effectively they are subsidized under this policy and the value of their land increases by the amount dR_3^{TR} in equation (2.31).

C. Urban Growth Boundary

Next consider the impact of an urban growth boundary, $\bar{x}_{UGB}$.

Efficiency Effects of the Urban Growth Boundary

The efficiency effects under an UGB can be expressed as (see Appendix A):

$$\frac{dR}{dO} = \underbrace{\int_0^{\bar{x}_{UGB}} \left[\frac{\partial p(Y,t,O,\bar{V},x)}{\partial O} h\left(S\left(Y,t,O,\bar{V},p_k,x\right)\right)\right] 2\pi x dx}_{dR^{CO}} + \underbrace{(r_u(Y,t,O,\bar{V},p_k,\bar{x}_{UGB}) - r_a) 2\pi \bar{x} \frac{d\bar{x}}{dO}}_{dR^S} \quad (2.32)$$

A comparison of (2.32) with (2.28) reveals that, since both policies are set to achieve the same amount of land preservation, from an efficiency perspective the two instruments are equivalent.

Distributional Impacts of the Urban Growth Boundary

The main difference between the UGB and the development tax is in the distributional impacts of the policy to the different landowners. The change in the return to land under an UGB for developers who allocate land to residential use both prior and post policy is given by:

$$\frac{dR_1}{dO} = \underbrace{\int_0^{\bar{x}_{UGB}} \left[\frac{\partial p(Y,t,O,\bar{V},x)}{\partial O} h\left(S\left(Y,t,O,\bar{V},p_k,x\right)\right) \right] 2\pi x dx}_{dR^{CO}} \tag{2.33}$$

Equation (2.33) distinguishes from (2.29) in the absence of the net tax effect term, dR^{NT}. For this class of landowners, the UGB is clearly preferable to the development tax. The change in the return to land under an UGB for developers who alter their behavior by changing land uses is given by:

$$\frac{dR_2}{dO} = \underbrace{(r_u(Y,t,O,\bar{V},p_k,\bar{x}_{UGB}) - r_a) 2\pi \bar{x} \frac{d\bar{x}}{dO}}_{dR^S} \tag{2.34}$$

A comparison of (2.34) and (2.30) suggests, for the same amount of land saved, this group of landowners is worse off under the UGB compared to the development tax. In fact, the key difference between this policy and the development tax is that it does not raise revenues for the government and therefore does not subsidize agricultural land. Finally, the impact of the UGB on landowners who allocate their land to agriculture pre and post policy is given by:

$$\frac{dR_3}{dO} = 0 \tag{2.35}$$

Because the UGB does not generate revenues, this policy will not affect this group of agents.

D. Property Tax

Next consider the impacts of a revenue-neutral tax t_H per unit of housing with revenues distributed lump sum to all landowners[8]. Let g_{t_H} be the government transfer to each landowner under this policy.

Efficiency Effects of the Property Tax

The efficiency effects of a property tax t_H can be expressed as

$$\frac{dR}{dO} = \underbrace{\int_0^{\bar{x}_{t_H}} \left[\frac{\partial p(Y,t,O,\overline{V},x)}{\partial O} h\big(S\big(Y,t,O,\overline{V},p_k,x\big)\big) \right] 2\pi x dx}_{dR^{CO}} + \underbrace{\left[r_u(Y,t,O,\overline{V},p_k,\bar{x}_{t_H}) - r_a \right] 2\pi \bar{x} \frac{d\bar{x}}{dO}}_{dR^S} +$$

$$+ \underbrace{\int_0^{\bar{x}_{t_H}} t_H \frac{\partial h(S(\cdot))}{\partial S(\cdot)} \frac{\partial S(Y,t,O,\overline{V},p_k,t_H,x)}{\partial t_H} \frac{dt_H}{dO} 2\pi x dx}_{dR^K} \tag{2.36}$$

The efficiency effects of the property tax differ from the development tax or the UGB due to the additional *adverse height effect* denoted by dR^K in equation (2.36). This *adverse height effect* reflects the facts that the property tax penalizes capital (in addition to land), and consequently decreases the optimal structural density chosen by landowners.

Distributional Impacts of the Property Tax

The impact of this property tax on landowners who allocate land to residential use prior and post policy is:

$$\frac{dR_1}{dO} = \underbrace{\int_0^{\bar{x}_{t_H}} \left[\frac{\partial p(Y,t,O,\overline{V},x)}{\partial O} h\big(S\big(Y,t,O,\overline{V},p_k,x\big)\big) \right] 2\pi x dx}_{dR^{CO}} + \underbrace{\int_0^{\bar{x}_{t_H}} \frac{dg_{t_H}}{dO} 2\pi x dx}_{dR_1^{TR}} +$$

[8] Brueckner [10] and Brueckner and Kim [12] study the impact of property taxes on urban spatial structure but do not decompose the efficiency channels exploited by this policy instrument.

$$+\underbrace{\int_0^{\bar{x}_{t_H}}\left[p\left(Y,t,O,\overline{V},x\right)\frac{\partial h(S(\cdot))}{\partial S(\cdot)}\frac{\partial S(Y,t,O,\overline{V},p_k,t_H,x)}{\partial t_H}-p_k\frac{\partial S(Y,t,O,\overline{V},p_k,t_H,x)}{\partial t_H}\right]\frac{dt_H}{dO}2\pi x dx}_{dR^H}-$$

$$-\underbrace{\int_0^{\bar{x}_{t_H}}\left[\frac{dt_H}{dO}h\left(S\left(Y,t,O,\overline{V},p_k,t_H,x\right)\right)+t_H\frac{\partial h(S(\cdot))}{\partial S(\cdot)}\frac{\partial S(Y,t,O,\overline{V},p_k,t_H,x)}{\partial t_H}\right]2\pi x dx}_{dR^T} \tag{2.37}$$

From (2.37) it is not possible to infer a priori if the property tax is preferable (or not) to the previous policies. (2.37) shows three impacts to landowners who keep their land in residential use after the policy is in place. On the one hand, this class of landowners receives the capitalization effect (dR^{CO}) and a transfer from the government in the amount of dR_1^{TR}. But on the other hand, they bear the entire property tax bill (dR^T) which affects their optimal density decisions and thus, their variable housing profit (dR^H). Therefore, a comparison between (2.37) and (2.29) reveals that if $dR_1^{TR}-dR^T$ (from equation (2.29)) is smaller than $dR_1^{TR}-dR^T+dR^H$ (from equation (2.37)), the development tax will be preferable. And a comparison between (2.37) and (2.33) shows that if $dR_1^{TR}-dR^T+dR^H$ (from equation (2.37)) is positive then the property tax will be preferred over the UGB. Our simulation results will help us to quantify these issues and clarify the rankings of instruments. The impact of the property tax on landowners who altered their behavior in response to the policy is given by:

$$\frac{dR_2}{dO}=\underbrace{(r_u(Y,t,O,\overline{V},p_k,\bar{x}_{t_H})-r_a)2\pi\bar{x}\frac{d\bar{x}}{dO}}_{dR^S}+\underbrace{\int_{\bar{x}_{t_H}}^{\bar{x}}\frac{dg_{t_H}}{dO}2\pi x dx}_{dR_2^{TR}} \tag{2.38}$$

Similar to the development tax and the UGB, under the property tax this set of landowners will bear the full cost from the *size effect*. However, they will prefer a property tax to an UGB. Also a comparison between (2.38) with (2.30) shows if the amount of transfer received under a property tax is greater than under a development tax then the former policy will be preferred over the latter to this set of landowners. Finally, like the development tax, landowners who allocate land to agriculture are subsidized under the property tax. Again, to the extent that the property tax may generate more revenues than the development tax for the same amount of land saved, this class of agents may prefer the property tax to any other instrument. Their welfare change is given by:

$$\frac{dR_3}{dO} = \underbrace{\int_{\bar{x}}^{\bar{m}} \frac{dg_{t_H}}{dO} 2\pi x dx}_{dR_3^{TR}} \tag{2.39}$$

E. Gasoline Tax

Finally, consider the impact of a gasoline tax t_G with revenues distributed lump sum among all households. Let g_{t_G} be the government transfer to each household. To better understand the impacts of the gasoline tax in the model, consider two distinct households. For a household living at the city center it is likely that the amount of government transfer received more than compensates the amount of tax paid, because the gasoline tax bill increases with distance from the CBD. In sharp contrast, for a household located at the suburbs, it is likely that the amount of tax paid outweighs the transfer. Therefore, the gasoline tax essentially redistributes income to households located towards the city core. As a consequence, households will alter their bids for housing depending on their location.

Efficiency Effects of the gasoline tax

The efficiency effects of a gasoline tax t_G are given by:

$$\frac{dR}{dO} = \underbrace{\int_0^{\bar{x}_{t_G}} \left[\frac{\partial p(Y,t,O,\bar{V},x)}{\partial O} h\big(S\big(Y,t,O,\bar{V},p_k,x\big)\big)\right] 2\pi x dx}_{dR^{CO}} + \underbrace{(r_u(Y,t,O,\bar{V},p_k,\bar{x}_{t_G}) - r_a) 2\pi\bar{x} \frac{d\bar{x}}{dO}}_{dR^S} +$$

$$+ \underbrace{\int_0^{\bar{x}_{t_G}} \left[\frac{\partial p(Y,t,O,\bar{V},g_{t_G} - t_G x, x)}{\partial (g_{t_G} - t_G x)} h\big(S\big(Y,t,O,\bar{V},p_k,x\big)\big)\right] \frac{d(g_{t_G} - t_G x)}{dO} 2\pi x dx}_{dR^Y} \tag{2.40}$$

The key difference between this policy and the development tax or the UGB is given by the term dR^Y in (2.40), which reflects the *disposable income effect*. This effect can be an efficiency gain (or loss), depending on whether the overall change in disposable income translates into higher (or lower) bids for housing. A priori, from an efficiency perspective, it is not possible to determine from the analytical model whether this instrument would be preferred to any other instrument. In our simulation model we are able to quantify the magnitude of the disposable income effect and, therefore, rank the instruments.

Distributional Impacts of the gasoline tax

The impact of a gasoline tax on landowners who continue to allocate their land to residential use is given by:

$$\frac{dR_1}{dO} = \underbrace{\int_0^{\bar{x}_{tG}} \left[\frac{\partial p(Y,t,O,\bar{V},x)}{\partial O} h\big(S\big(Y,t,O,\bar{V},p_k,x\big)\big) \right] 2\pi x dx}_{dR^{CO}} + \underbrace{\int_0^{\bar{x}_{tG}} \left[\frac{\partial p(Y,t,O,\bar{V},g_{tG}-t_G x,x)}{\partial (g_{tG}-t_G x)} h\big(S\big(Y,t,O,\bar{V},p_k,x\big)\big) \right] \frac{d(g_{tG}-t_G x)}{dO} 2\pi x dx}_{dR^Y} \tag{2.41}$$

(2.41) suggests that, like the previous policies, this set of landowners will fully capture the welfare gain from the *capitalization effect*. In addition, this set of agents can have an additional source of welfare gain, captured by the term dR^Y in (2.41), if their plot of land is located in an area where households are effectively subsidized under the gasoline tax. In this case, households would bid higher prices for housing and therefore the value of land would increase. A key insight from our model is that, depending on the *location* of their plots of land, landowners could be made better off under this policy. Therefore, it is certainly the case that there exists a sub-group of landowners who allocate land for residential use, for which the gasoline tax is the preferred instrument. For landowners who alter behavior in response to the gasoline tax and for landowners who continue to allocate land to agriculture, the gasoline tax is equivalent to the UGB in the sense that it does not alter these landowners land values. Therefore the welfare effects for the group of landowners who switch uses and to the group of landowners who keep land in agriculture use are respectively given by:

$$\frac{dR_2}{dO} = \underbrace{\left(r_u(Y,t,O,\bar{V},p_k,\bar{x}_{t_G}) - r_a\right)2\pi\bar{x}\frac{d\bar{x}}{dO}}_{dR^S} \tag{2.42}$$

$$\frac{dR_3}{dO} = 0 \tag{2.43}$$

3. Numerical Model

In this section we numerically examine the welfare effects of the alternative policies described in section 2 and their distribution across landowners within a city[9]. Subsection A specifies the functional forms and subsection B discusses the parameters values used to calibrate the model. In Bento et al. [4], we provide further discussion of the simulation model.

A. Model Structure

Household Behavior

Consistent with the analytical model, households derive utility from a housing good, H , a composite good, Z , and from open space O. Households´ preferences are represented by a Cobb Douglas utility function:

$$U(H,Z,O) = H^{\alpha}Z^{(1-\alpha)}(1+\delta\sqrt{O}) \tag{3.1}$$

[9] The simulation model was solved using *Mathematica*. Details of the computer programs are available from the authors upon request.

where α denotes the percentage of income net of transportation costs spent on housing and δ is a positive constant[10].

Landowners Behavior

We use a constant-elasticity-of-substitution (CES) form to describe the housing production function:

$$H^s(K,L)=\left[\beta K^{\frac{\sigma-1}{\sigma}}+(1-\beta)L^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},\ \sigma\neq 1 \tag{3.2}$$

where $H^s(K,L)$ is housing supply, K is structural capital, L is land, β is the share of capital in the production function and σ is the elasticity of substitution between capital and land.

B. Parameter values

We now discuss the parameter values used in our benchmark simulations. The Bureau of Labor Statistics-CE (2001) as well as the U.S. Department of Commerce-Bureau of Economic Analysis (2001) reported for the year 2000 that on average, American households spent 33% of their disposable income on housing and around 17% on transportation, 92% of which was on automobile transportation. It is also reported in 2000, American households had an average annual disposable income of \$38045 and average total monetary cost of owing and operating an automobile of 0.51 cents per mile. Given these statistics, we have chosen a value of $\alpha=0.4$, a disposable income $Y=\$40000$ and a commuting cost parameter per mile/year $t=\$600$. Also the unitary price and income elasticities implied by our Cobb Douglas utility function are well within the range of values found in empirical studies (Harmon [16]).

[10] In the analytical model we have assumed separability in the utility function between private goods and open space for tractability reasons. In the numerical model we are able to relax this assumption. We note, however, that similar conclusions apply in general.

The agriculture rent value was chosen based on the Farm Real Estate Value[11] Indicator reported by the United States Department of Agriculture for the year 2000 and set equal to $1000 per acre per year, corresponding to a rent per square mile of $640000.

Based on empirical studies which estimate the elasticity of substitution between land and capital in the structure production function (review in McDonald [17]), the current wisdom is that σ lies between 0.6 and 0.8. On the basis of this review we set σ equal to 0.8 and a value of 0.95 for the share of capital, β , in the housing production function.

The unitary price of capital structures varies widely depending on the type of housing built (apartments versus single houses), type and quality of materials used and topographic conditions. We have used the construction cost data from the R.S. Means Company to infer the cost of capital to be used in our simulation model[12]. Given the numbers reported we have used $100 as a reasonable guess for the unitary cost of capital.

The exogenous radius of total available land, $\overline{m}$, was set equal to 20 miles and finally the parameter δ as well as the exogenous utility level, $\overline{V}$, were set arbitrarily to generate realistic cities. Their values are 0.065 and 2200, respectively.

Prior to government intervention to control excessive urban growth, the city has a radius of 12.3723 miles and approximately one and a half million people living within its boundaries[13]. Table 1 summarizes our benchmark metropolitan area, that is, the urban equilibrium prior to any government intervention.

[11] Farm Real Estate Value is defined as the value at which all land and buildings used for agriculture production could be sold under current market conditions, if allowed to remain on the market for a reasonable amount of time. It is an indicator of the financial condition of the farm sector and its value is influenced by net returns from agricultural production, capital investment in farm structures, interest rates, government commodity programs and nonfarm demands for farmland.

[12] The Means data on construction costs include material costs, labor costs and equipment costs. Given that no land costs are included, the construction cost data reported by the R.S. Means Company are for the physical structure itself. In general, the marginal construction cost of an apartment is the price of building up. As a basic number, the Means data suggests that construction costs for a building in a typical high rise of from 8 to 24 stories was nearly $110 per square foot in New York City in 1999.

[13] For an assumed 3 people per household.

4. Numerical Results

This section presents results from the numerical model. Subsections A and B compare the marginal welfare effects of the different anti-sprawl policies and the distribution of total welfare effects to landowners located at different distances from the CBD. It should be noted our emphasis is on qualitative, rather than quantitative, differences across policies and therefore to illustrate the welfare effects of the anti-sprawl policies discussed in the analytical model. The quantitative differences can vary depending on housing production parameters, level of exogenous agricultural rent and utility-function parameters, which determine the relative contributions of the *size*, *capitalization*, *(adverse) height*, *net-tax* and *disposable income effects.* Finally, subsection C explores the sensitivity of the results in subsections A and B to some additional parameters variations.

A. Marginal Welfare Effect to Landowners

We first examine the marginal welfare effects to landowners of alternative anti-sprawl policies. In figure 1, on the horizontal axis we measure percentage of land saved (up to 15%) and on the vertical axis marginal welfare effect, where a positive value indicates a benefit and a negative value indicates a cost. The main goals of this figure are to decompose the different sources of efficiency discussed in section 2 and discuss their contribution to the overall welfare of the different policies.

$MW^{Development\&UGB}$ represents both the marginal welfare effect of the development tax and the UGB since, as already shown in the analytical model these instruments are equivalent from a welfare perspective. This curve reflects the two opposing efficiency channels exploited by these two instruments: the *capitalization* and the *size effects*. $MW^{Development\&UGB}$ has a positive intercept due to the capitalization of open space, and is downward sloping, reflecting the increasing marginal cost of saving land. The crucial point from this curve is that while the *capitalization* *effect* is significant for low levels of land saved, the contribution of the *size effect* to the costs of the policy quickly increases. For example, doubling the percentage of land saved from 5 to 10% more than halves the marginal benefit. This is not surprising, since as more land gets saved, we move towards the city center where housing prices are higher and thus residential land is more valuable. From the figure, the optimal level of land preservation under the development tax and UGB is approximately 12%, where the $MW^{Development\&UGB}$ curve intersects the horizontal axis. After 12% the costs of preserving land would outweigh the benefits.

$MW^{\Pr oprety}$ shows the marginal welfare effect of saving land under the property tax. The vertical distance between this curve and the $MW^{Development\&UGB}$ curve reflects the *adverse height effect*. This effect is a welfare loss because the property tax penalizes simultaneously land and capital. Because of the *adverse height effect*, the optimal level of savings under the property tax is 4.5%, which is substantially less than the development tax and UGB. If the goal is to perverse land at the urban fringe, a property tax is a blunt instrument.

Finally, MW^{Gas} shows the marginal welfare effect under the gasoline tax. This curve represents the $MW^{Development\&UGB}$ curve plus the marginal welfare effect from the *disposable income effect*. Under our central parameter estimates, this figure suggests that the welfare cost from the *disposable income effect* is always lower than that from the *adverse height effect*, which means from a welfare perspective the gasoline tax is preferable to the property tax. Under the gas tax, the optimal level of savings is 7%. This is greater than the property tax, but still only about half of the amount would be saved under the development tax and UGB.

B. Distribution of Welfare Effects to Landowners along the city

We now consider the distribution of welfare effects to different landowners across the city. Figure 2 compares the total welfare effect to different landowners of saving 12% of land. 12% was chosen as a point of comparison because it is the optimal level of land savings under the development tax and UGB. Choosing a different level of savings merely alters the magnitudes, but not the relative structure of the distributional effects.

TW^{UGB} shows the distribution of the total welfare effect throughout the city under the UGB . Consistent with the analytical model, the UGB effectively benefits landowners inside the city's urban area. In fact, landowners at the city center capture the greatest welfare gain from the *capitalization effect*. Under our central estimates this source of welfare gain is significant and therefore TW^{UGB} is positive inside the new city boundary. TW^{UGB} also shows that this policy is neutral for landowners who were allocating land to agricultural use prior to the policy intervention. Finally, all the burden of the policy falls in the group of landowners who will be restricted from allocating land to residential use. These are the set of landowners who own land located between the city boundary prior to the policy intervention (located at 12.37 miles in the figure) and the new boundary (located at 11.61 miles from the CBD). They bear the full cost of the *size effect*. Note that this negative welfare effect equals the difference between the residential rent (under no policy) and the agricultural rent, and therefore this negative welfare effect is decreasing as we move further away from the CBD.

In contrast, the distribution of total welfare effects under the development tax, denoted by $TW^{Development}$, is very different than under the UGB. While the UGB mainly benefits landowners at the city center, the development tax uniformly penalizes these landowners and subsidizes landowners who do not develop. Therefore the total welfare effect under the development tax is negative and decreasing up to the new city boundary, as the constant costs from the *net tax effect* outweigh the benefits from the *capitalization effect*. The set of landowners who own land located between the old and the new city boundaries are better off with the development tax than under the UGB. This is because part of the revenues generated by this tax is returned to them as shown in (2.30). Finally landowners who keep their land under agricultural use are also substantially better off under the development tax (relative to the UGB).

Next consider the effects of a property tax. The curve $TW^{\Pr operty}$ shows the distribution of total welfare effects under the property tax. Unlike the development tax, the property tax falls both on land and capital infrastructures. As a consequence, the property tax alters the optimal landowners' decision on density. The closer to the central business district, the higher the burden from the property tax because density levels decrease with distance. Another interesting point is that compared with the development tax, for the same amount of land saved, the property tax generates more revenue. For the set of landowners whose land is located between the old and the new boundaries, as well as for those who allocate land to agricultural use, the property tax is always the preferred instrument. For the majority of landowners who keep land in residential use this instrument implies a large negative total welfare effect when compared to the welfare effects imposed by the development tax or the UGB.

Finally consider the impacts of a gasoline tax, represented in figure 2 by TW^{Gas}. This curve contrasts the most with the property tax because it subsidizes landowners at the city center. The gasoline tax is a tax on miles driven with revenues returned lump sum to all households. As a consequence, the further away from the city a household lives, the higher their tax will be for the same amount of return. Hence, the total welfare curve decreases as we move away from the CBD. For landowners located after the new boundary, this policy is equivalent to the UGB. This is because the revenues were distributed to households instead to landowners. The key insight from figure 2 is that space, in other words the location of land, determines the relative winners and losers from the different anti-sprawl policies.

C. Sensitivity Analysis

We refer the reader to Bento et al. [4] for a careful discussion of sensitivity analysis. Here we simply note that, for the range of parameter values chosen, though the size of the cities and heights of the cities varied dramatically, the efficiency rankings and the distributional effects of the policies remained the same, even if the resulting values were very different than the benchmark.

5. Conclusions

This paper has employed analytical and numerical general equilibrium models to compare the efficiency and distributional impacts of a range of anti-sprawl policy instruments aimed at saving the same amount of land. We find that, from an overall efficiency perspective, development taxes and urban growth boundaries are equivalent instruments and the most effective anti-sprawl policies. Under plausible parameter assumptions, it is optimal to preserve 12% of land under these policies. In contrast, our results indicate that because the gasoline tax and the property tax are not direct instruments to combat sprawl, the resulting optimal amounts of land preserved are substantially less. For the property tax, for example, it would be optimal to only preserve 40% of the amount of land that would have been saved under a development tax or an urban growth boundary.

We also find that if the choice of anti-sprawl instruments is based on distributional considerations, then it is no longer clear the development tax or the urban growth boundary will be the preferred instruments to all landowners. In fact, our results suggest the preferred instrument is closely related to the *location* of land. In particular, we are able to divide the city into three areas: the urban city core, the urban suburbs and rural area. For the landowners located at the urban city core, the gasoline tax is always the preferred instrument because landowners will have the largest welfare gain. For example, at 5 miles from the CBD, the welfare gain from of saving 12% of land using a gasoline tax is roughly twice as large as under the urban growth boundary. For this class of agents, it is also the case that the property tax is the less desired instrument. For landowners located in the urban suburbs, that is, between 7 to about 10 miles from the CBD, the UGB dominates any other instrument the development tax. Finally in rural areas, the property tax is always the preferred instrument because it subsidizes agricultural use.

This set of landowners suffers no change in their welfare levels under the urban growth boundary or the gasoline tax.

Some limitations of this study deserve attention. First, although most US cities have a polycentric structure (Anas et al. [1], Anas and Xu [2], Anas and Rhee [3]), we have conducted our analysis within a monocentric framework. The reason is that a monocentric setting allows us to address the topics of study while keeping the analysis tractable. Furthermore, we expect our monocentric analyzes to yield insights that carry over to more sophisticated polycentric configurations.

Second, because we also do not model firms' location decisions or households working decisions we are not able to capture the efficiency impacts of anti-sprawl policies in other markets such as the labor market besides the land and housing markets. In a recent paper, Anas and Rhee [3] address some of these issues. We see our paper as a complement to their analysis, in the sense that we provide a comparison across a larger set of policy instruments.

Finally, a third caveat in our study concerns the way open space is modeled. For simplicity we focused the analysis only on the value of open space outside city limits. However, individuals may also value open space inside the city and it might be optimal for developers to provide open space together with housing (Bento et al. [6], Walsh [21]).

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Appendix A. Analytical derivations of (2.32), (2.36) and (2.40)

Deriving Equation (2.32)

Note that after an UGB is in place, there is a change in land use for landowners between $\left[\bar{x}_{UGB}, \bar{x}\right]$. The change in land value for these landowners is given by:

$$(r_u(Y,t,O,\overline{V},p_k,\bar{x}_{UGB}) - r_a)2\pi\bar{x}\frac{d\bar{x}}{dO} \tag{A.1}$$

Differentiating the city total aggregated land value equation (2.14) with respect to O while taking into account (A.1) and inserting the close condition (2.10) and (2.20) gives (2.32).

Deriving Equation (2.36)

The return per acre to land in residential use at location x under the property tax is given by:

$$\begin{aligned} r_u^{t_H}(\cdot,x) = {} & (p(Y,t,O,\overline{V},x) - t_H)h(S(Y,t,O,\overline{V},p_k,t_H,x)) - p_k S(Y,t,O,\overline{V},p_k,t_H,x) \\ & + g_{t_H} \end{aligned} \tag{A.2}$$

The return in agriculture use under a property tax is given by:

$$r_a + g_{t_H} \tag{A.3}$$

Differentiating (2.14) with respect to O and taking into account (2.10), (2.20), (A.2), (A.3) yields:

$$\begin{aligned} \frac{dR}{dO} = {} & \underbrace{\int_0^{\bar{x}_{t_H}} \left[\frac{\partial p(Y,t,O,\overline{V},x)}{\partial O} h\left(S\left(Y,t,O,\overline{V},p_k,x\right)\right)\right] 2\pi x dx}_{dR^{CO}} + \underbrace{\left[r_u(Y,t,O,\overline{V},p_k,\bar{x}_{t_H}) - r_a\right] 2\pi\bar{x}\frac{d\bar{x}}{dO}}_{dR^S} - \\ & - \underbrace{\int_0^{\bar{x}_{t_H}} \left[\frac{dt_H}{dO} h\left(S\left(Y,t,O,\overline{V},p_k,t_H,x\right)\right) + t_H \frac{\partial h(S(\cdot))}{\partial S(\cdot)} \frac{\partial S(Y,t,O,\overline{V},p_k,t_H,x)}{\partial t_H} \right] 2\pi x dx}_{dR^T} + \\ & + \underbrace{\int_0^{\bar{x}_{t_H}} \left[p\left(Y,t,O,\overline{V},x\right) \frac{\partial h(S(\cdot))}{\partial S(\cdot)} \frac{\partial S(Y,t,O,\overline{V},p_k,t_H,x)}{\partial t_H} - p_k \frac{\partial S(Y,t,O,\overline{V},p_k,t_H,x)}{\partial t_H} \right] \frac{dt_H}{dO} 2\pi x dx}_{dR^K} + \end{aligned}$$

$$+\underbrace{\int_0^{\overline{m}} \frac{dg_{t_H}}{dO} 2\pi x dx}_{dR^{TR}} \tag{A.4}$$

We know that the optimal density level $S(Y,t,O,\overline{V},p_k,t_H,x)$ is implicitly given:

$$\left[p(Y,t,O,\overline{V},x) - t_H\right] \frac{\partial h(S)}{\partial S} = p_k \tag{A.5}$$

The government budget constraint under a property tax is given by:

$$\int_0^{\overline{m}} g_{t_H} 2\pi x dx = \int_0^{\bar{x}_{t_H}} t_H h(S(Y,t,O,\overline{V},p_k,t_H,x)) 2\pi x dx \tag{A.6}$$

Differentiating (A.6) with respect to O and plugging it into (A.4) while taking into account (A.5) yields (2.36).

Deriving Equation (2.40)

Under a gasoline tax, the new household budget constraint can be written as:

$$Y - tx + (g_{t_G} - t_G x) = Z + pH \tag{A.7}$$

The housing bid rent function under the gasoline tax is thus given by:

$$p(Y,t,O,\overline{V},g_{t_G} - t_G x, x) \tag{A.8}$$

Total differentiating (A.8) with respect to O gives:

$$\begin{aligned}\frac{dp(Y,t,O,\overline{V},g_{t_G} - t_G x, x)}{dO} &= \frac{\partial p(Y,t,O,\overline{V},g_{t_G} - t_G x, x)}{\partial O} + \\ &+ \frac{\partial p(Y,t,O,\overline{V},g_{t_G} - t_G x, x)}{\partial (g_{t_G} - t_G x)} \frac{d(g_{t_G} - t_G x)}{dO}\end{aligned} \tag{A.9}$$

The return per acre to land in residential use at location x under the gasoline tax is:

$$\begin{aligned} r_u^{t_G}(\cdot,x) = {} & p(Y,t,O,\overline{V},g_{t_G} - t_G x, x) h(S(Y,t,O,\overline{V},p_k,t_G,g_{t_G},x)) - \\ & - p_k S(Y,t,O,\overline{V},p_k,t_G,g_{t_G},x)\end{aligned} \tag{A.10}$$

The optimal density level $S(Y,t,O,\overline{V},p_k,t_G,g_{t_G},x)$ is implicitly given by:

$$p(Y,t,O,\overline{V},g_{t_G}-t_G x,x)\frac{\partial h(S)}{\partial S}=p_k \quad \text{(A.11)}$$

Differentiating (2.14) with respect to O and inserting (2.10), (2.20), (A.9), (A.10) and (A.11) yields (2.40).

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Table 1-Benchmark Equilibrium Values

Description variables	**Benchmark values**
Radius of the city (miles)	12.3723
Total residential land (square miles)	480.897
Total farmland land (square miles)	775.74
Total households in the city	535073
Total residential land value (in dollars)	$1.34894*10^9
Household Utility level	2200
Average price of residential land (per acre/year)	$4,382.89

Average price of farmland (per acre/year)	$1,000
Average rental housing price (per square foot)	$211.16
Structural density at CBD (per acre)	741.608
Structural density at City Edge (per acre)	66.5278
Population density at CBD (per acre)	17.7243
Population density at City Edge(per acre)	1.761873

Figure 1: Marginal Welfare Effect to Landowners

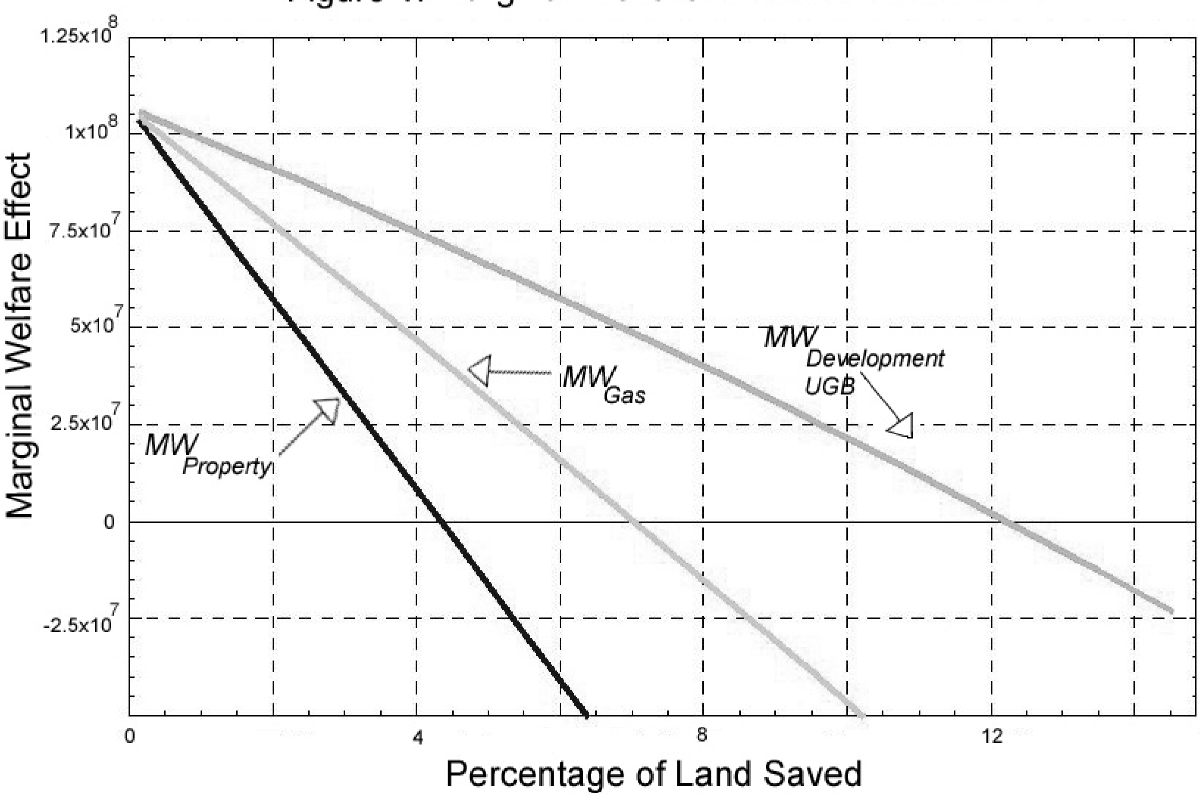

Figure 2: Total Welfare Effect to Landowners Saving 12% of Land